UCRL-51839

ATMOSPHERIC RELEASE ADVISORY CAPABILITY (ARAC): DEVELOPMENT AND PLANS FOR IMPLEMENTATION

Marvin H. Dickerson
Richard C. Orphan

June 5, 1975

Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore

MASTER

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $____*; Microfiche $2.25

*Pages	NTIS Selling Price
1-50	$4.00
51-150	$5.45
151-325	$7.60
326-500	$10.60
501-1000	$13.60

Distribution Category
UC-11

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California/94550

UCRL-51839

ATMOSPHERIC RELEASE ADVISORY CAPABILITY (ARAC): DEVELOPMENT AND PLANS FOR IMPLEMENTATION

Marvin H. Dickerson

Richard C. Orphan

MS. date: June 5, 1975

ATMOSPHERIC RELEASE ADVISORY CAPABILITY (ARAC): DEVELOPMENT AND PLANS FOR IMPLEMENTATION

Abstract

The Atmospheric Release Advisory Capability (ARAC) is an ERDA-sponsored service planned for nuclear facilities which require a means of real-time prediction of the extent of health hazards that may result from a release of radionuclides or other toxic materials. Since 1973 when the ARAC concept was initiated, a joint feasibility study has been conducted by Lawrence Livermore Laboratory and Savannah River Laboratory, and a prototype component of the system has been built and placed in operation. During the next three years plans are to implement the ARAC service for certain ERDA nuclear facilities. This report is written to provide a brief description of the ARAC concept, to discuss the progress to date, to outline future plans for developing the system, and to provide potential users with the benefits, requirements, and costs involved in using the ARAC service.

I. Introduction

Facilities that handle radioactive materials have a paramount obligation for the protection of both their operating personnel and the public at large. In spite of a remarkable overall record of safety, the nuclear industry faces a great challenge in minimizing potential damage which could result from nuclear accidents and incidents. It must be recognized that the advent of nuclear materials introduced new forms of hazard subject to technical controversy and often misunderstood by the layman. An inherent fear of the effects of radioactivity tends to exist on the part of the public, and special care is necessary to avoid undue jeopardy to the potential national asset which nuclear energy represents. Continuation of a favorable nuclear safety record depends not only on strict adherence to standards and regulations, but also on extra effort at the local level to foresee any potential occurrences and to plan emergency actions.

Although the growing nuclear power industry on the whole is engaging this problem, the ERDA nuclear sites (research and production facilities) have found a special responsibility in this regard. Because they have been participants in the initial pioneering effort in the field and agents for an enormous part of the overall handling of nuclear materials for the nation, they have always given special emphasis to safety and accident prevention. Federal direction and assistance in matters of nuclear safety are available; nevertheless, the safety aspects of nuclear material handling must ultimately rest upon the diligent effort applied at each facility.

In the execution of this responsibility the ERDA nuclear sites are typically faced with a number of questions such as the following:

- What health hazards to operating personnel and the public would result in the event of a nuclear accident or incident?

- More specifically, how fast and to what extent will a release of radioactive materials diffuse under a particular set of circumstances and weather conditions?

- What kind of predictive information can be derived in order to permit adequate dec sions in an emergency?

- How can routine releases of radioactive materials be planned so as to minimize potential impact on the surrounding environment?

ERDA is in the process of establishing a means of assisting the management at ERDA nuclear sites in responding to these types of questions. Under the cognizance of the DBER program, LLL has developed a centralized service to provide ERDA nuclear sites with real-time predictions of the consequences of an atmospheric release of radioactive materials. This service is called Atmospheric Release Advisory Capability (ARAC).[1]

II. Purpose of ARAC

The chief purpose of ARAC is to provide responsible site officials with estimates of the effects of atmospheric releases of hazardous materials as rapidly and accurately as possible. ARAC would develop a series of advisories concerning emergency or routine atmospheric releases to assist the site in its planning. At the heart of the ARAC concept are the numerical models that provide real-time regional assessments based upon input data from the site. These models vary in complexity from a single-trajectory model to an interfaced set of advanced regional transport and diffusion models covering the distance range of ~10-100 km. The models, combined with other state-of-the-art technology for dose conversion and data handling and communication, permit a greatly improved but economical means for preuicting the effects of releases of toxic materials of any sort.

While the primary function of ARAC is to assist a site in emergency response, there are additional more routine uses intended for this service. Some examples are:

- Calculate and maintain an inventory of radioactivity in the source.

- Maintain an updated inventory of routine releases and their location in the environment.

- Calculate doses from routine operations.

- Perform sensitivity studies to ascertain changes in pathway drives that determine the biological impact possible from changes in site operations and in site location for projected facilities.

For a particular ERDA site, the ARAC concept would offer the following advantages:

- Predictive capability based on a local automated system. The ARAC site equipment would provide the means for locally applying atmospheric modeling techniques for close-in distances (~5 km).

- Links with advanced state-of-the-art predictive capability. The ARAC central facility would provide the results of newly developed regional modeling techniques and dose conversion data in real time. Access to large-scale computer systems and modern efficient data handling would permit countermeasure planning based on information products not readily available at an individual site.

- Emergency backup links. In the event of an accidental release, countermeasure planning could also be conducted away from the local site. Graphic display of data at several remote locations would permit coordination and alternative options.

- Minimal costs. The centralized basis of ARAC would permit economies not practical for individual sites.

When implemented, the ARAC would support the present ERDA role for assistance to operating nuclear sites in several important ways. These include, but are not limited to, the following:

- The quality of information and radiological advisories from ERDA would be improved due to the availability of real-time data and regional information.
- The predicted off-site radiological effects would include transient regional transport processes.
- Any off-site countermeasures and postemergency cleanup operations would have a basis for iterative improvement as actual radiological information is received.
- ARAC would serve as a focal point to develop future improvements in the assistance and advisories provided by ERDA.

III. Component Parts of ARAC

The ARAC system is built upon a communication and data acquisition network that allows each user to have rapid access to the central advisory products which in turn are based upon environmental data from the local site. Figure 1 shows the component parts of the ARAC system. Any number of nuclear/chemical facilities or sites within the U.S. can be serviced within the network. The national/global meteorological service, provided by the National Weather Service and/or the Air Force Global Weather Central, supplies meteorological data (observational data, analyses, forecasts) that are pertinent to each assessment. The central facility, through data and/or voice telecommunication links, provides the site with the regional assessment products that are calculated on the CDC 7600 class computers. If desired, ERDA or local officials may also receive the advisories at the same time. In the remainder of this chapter we discuss the manner in which the site receives the regional assessment calculations, the design and function of the central facility's data acquisition and communication system, and the use of the national/global meteorological services. Aspects of the regional modeling calculations and advisories are discussed in Chapter IV.

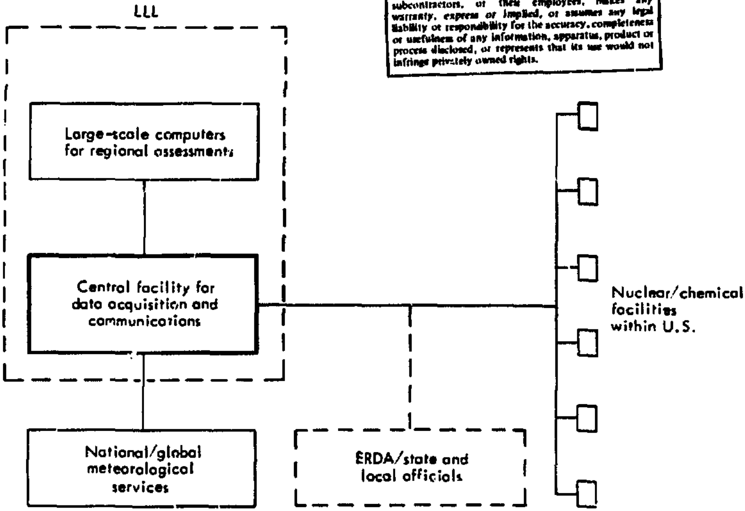

Fig. 1. Component parts of the ARAC system.

SITE FACILITY

Each ARAC-serviced site will have a minicomputer which furnishes local data acquisition, assessment, and communication capabilities. Examples of specific functions of the ARAC site facility are:

- Multiplexes the environmental sensors.
- Provides local data quality control.
- Continuously calculates and displays Gaussian diffusion estimates for close-in distances (out to approximately 5 km) using latest local meteorological data.
- Transmits local environmental measurements to the central facility.
- Receives and displays regional calculations from the central facility.

Since the site facility can perform certain important and relevant functions without a direct data link to the central facility (in the "stand-alone" mode), this part of the system was the first to be designed and tested. In FY 1975 LLL purchased the hardware and started the software development for the first operating ARAC site facility, which was located at LLL. The site equipment is shown in Fig. 2 being used in a laboratory environment; it consists mainly of the minicomputer with core memory, graphic display, and interfacing hardware. A

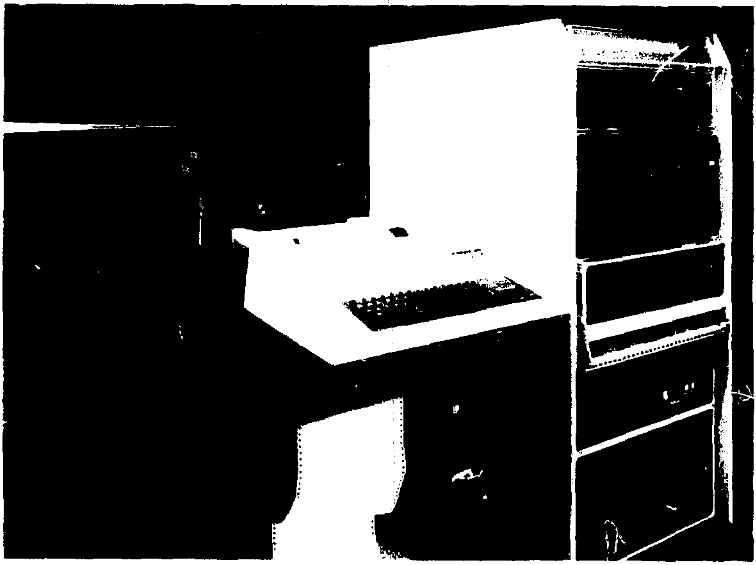

Fig. 2. Hardware used in the LLL prototype ARAC site facility.

printer/plotter used to obtain hardcopy output (not shown in this figure) is also part of the site system. Software written for the Livermore site facility can be customized to satisfy the local requirements for additional sites that are added to the ARAC system.

The interactive operating system for the site facility is designed to provide the user with what he needs, when he needs it, efficiently and with a minimum amount of effort on his part. Examples of the present capabilities available on the LLL site facility are shown in Figs. 3 through 8. Figure 3 shows the "menu" which lists the options that are available to the user on the graphic display of the minicomputer. By using the light pen or keyboard any of the items from 1 through 10 shown in Fig. 3 can be selected and displayed on the screen. For example, if one is interested in the normalized Gaussian diffusion calculation, based on the latest meteorological data from the tower, superimposed on the 5-km-radius local map, numbers 7 and 5 are selected via the light pen. This calculation is shown in Fig. 4. At the time this picture was taken the contour labels were not included; however, in the final version they will be added.

Figure 5 shows the 100-km-radius map of the Livermore region. This map is used as a reference for the trajectory and regional model calculations. The cross surrounded by the dash-dot square and solid diamond follows the light pen and allows the user to select and magnify the portion of the area enclosed by the square. This scaling also applies to the calculations that are overlaid on the map for reference. Presently the user has the scale options listed at the bottom of this figure. Figure 6 shows a scale of 100 km selected from this list and Fig. 7 shows an example of a trajectory computed and overlaid on this region. The trajectory is the line originating at LLL with the labels A, B, D, and G, which represent the locations of a hypothetical release after 1, 2, 4, and 7 hours. Apparent nonintersecting roads shown on this figure result from a coarse digitizing of the regional map which has now been corrected.

When the user wants to view the results of the regional model calculations received from the central facility, he selects number 9, and a "submenu" (Fig. 8) appears on the graphical display listing the output options that are available to him. Shown here are the calculations that would be available from the regional models within 30 to 40 minutes after notification of a release. Models used

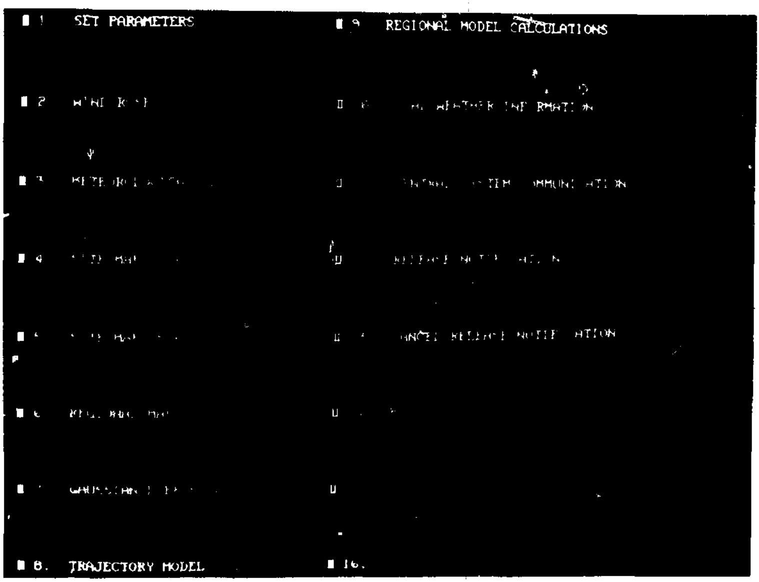

Fig. 3. "Menu" showing a list of optional displays and commands presently available on the LLL site facility.

Fig. 4. Gaussian diffusion calculation overlaid on a map of the area within 5 km of LLL.

to produce these calculations are discussed in the following chapter of this report. Results from these calculations are overlaid on the user-selected map, as are the trajectory calculations, such as those shown in Fig. 7. Any of these calculations that appear on the screen can be reproduced on one or more hardcopies by the printer/plotter.

As other users are added to the ARAC system, certain aspects of the site facility's software must be customized to fit the specific site requirements. Specifications for interfacing the site facility to the local environmental sensors are written and are available from Lawrence Livermore Laboratory. With certain modifications the site facility's hardware and software can be adapted to provide the ARAC advisories to ERDA officials or local officials at the same time they are sent to the site.

NATIONAL/GLOBAL METEOROLOGICAL SERVICE

Meteorological data from the National Weather Service (NWS) and/or Air Force Global Weather Central (AFGWC) would be received by the central facility minicomputer on a routine and special-request basis. These data would be stored and printed on hardcopy for analysis; certain data would be selected and formatted as input data for the trajectory calculation and the *regional* models. LLL is now serviced by NWS; we anticipate that our meteorological data acquisition facility will link to AFGWC to obtain grid-point-forecast meteorological data from their fine-mesh and boundary-layer models. AFGWC would also send us the latest global observational data and general forecast information for specific areas. Certain observational and forecast data would be received at LLL on a routine scheduled basis; in an emergency, supplemental data can be received by a special request. The design of the AFGWC meteorological data network is such that a minicomputer at a remote location can receive,

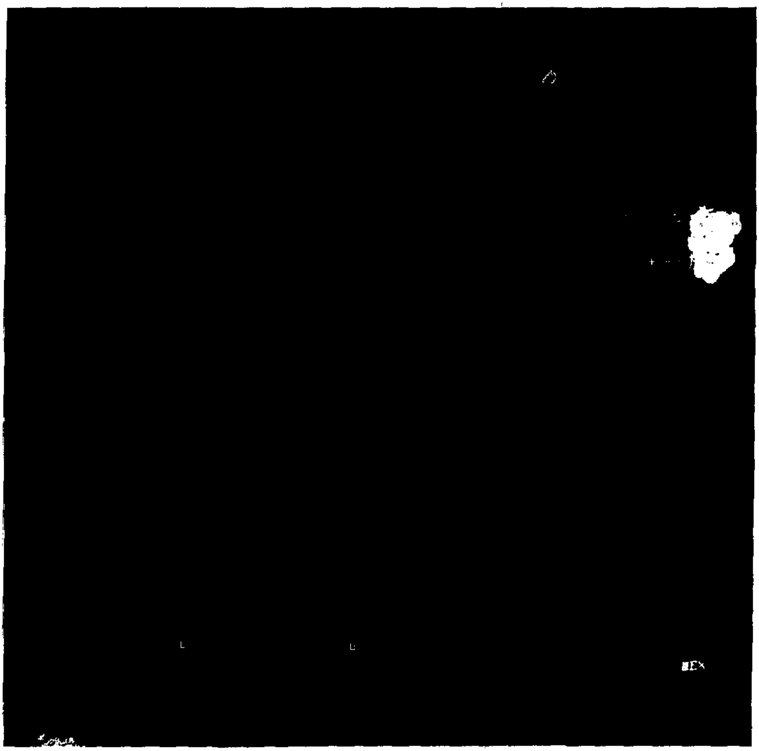

Fig. 5. Map of the area within a 100-km radius of LLL. The cross surrounded by the dash-dot square and solid diamond is used to select an area of the map for magnification.

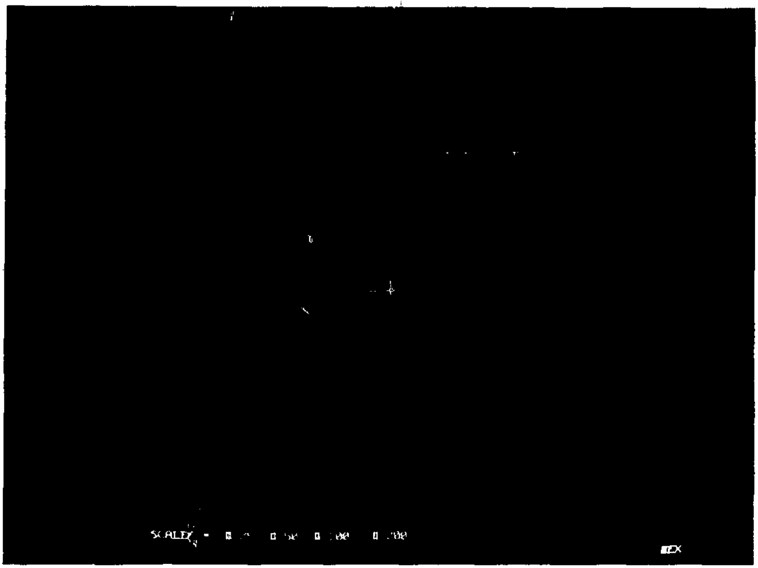

Fig. 6. The 100-km-radius LLL map with a dashed square enclosing the area that is chosen for magnification.

analyze, display, and store the meteorological data. This feature tremendously improves the efficiency of manipulating and utilizing large amounts of weather data.

During the next several years the NWS data will be received on facsimile charts and teletype output. These data will be used to supplement and back up the data we expect to receive from the AFGWC. However, the NWS plans to automate its meteorological service with the Automation of Field Operations and Services (AFOS) system within the next several years. When this system becomes operational, we plan to include it as part of our meteorological data acquisition facility.

CENTRAL FACILITY OF LLL

In the first section of this Chapter we discussed the communication link between the site and the central facility and gave examples of information that can be transmitted between them. Also we suggested that a communication link can be established between the central facility and selected ERDA, state, and local officials. We will now examine the role of the central facility in more detail.

The central facility serves as the focal point for data acquisition, assessments, and communications for the ARAC service. During normal operating conditions, site environmental data together with any site messages would be transmitted to the central facility on a scheduled 4-hour basis. The central facility would manipulate these data for storage and for making routine site environmental assessments.

In the event of a potential or real emergency, a data and voice communication link would immediately be established between the site and the central facility. At the same time, data would be requested from the meteorological data acquisition facility, and the regional model computer codes would be made available on the large computers. The meteorological data are stored in a computer-compatible format and can be retrieved, analyzed, and used to compute

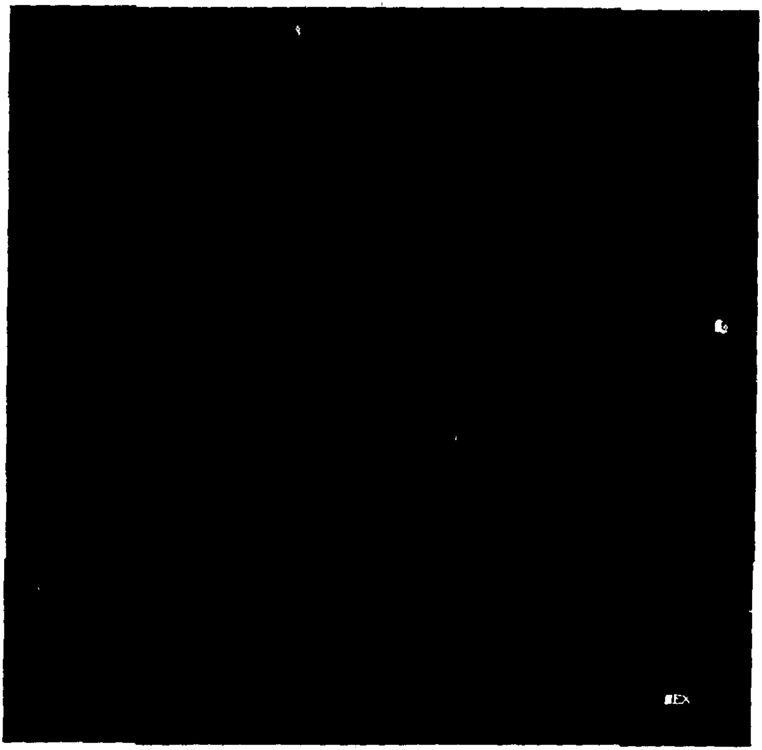

Fig. 7. A computed trajectory (the line originating at LLL with the A, B, D, and G labels) overlaid on the map selected from the dashed square shown in Fig. 6.

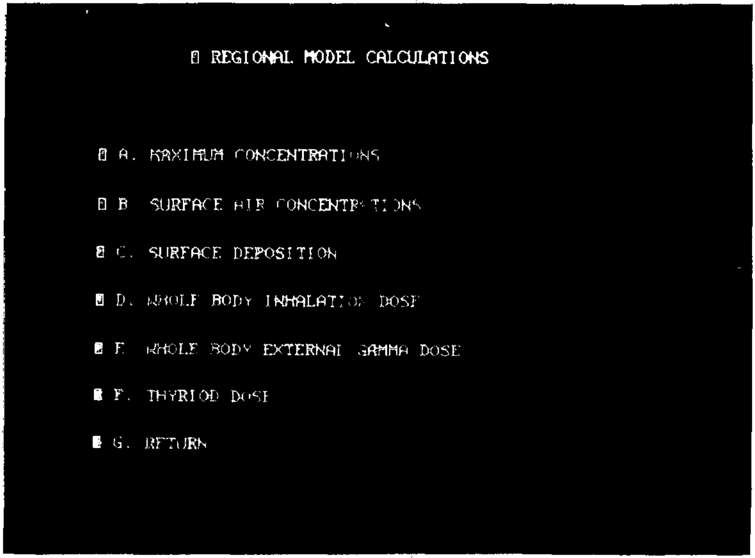

Fig. 8. A "submenu" showing the optional calculations available from the regional models.

a trajectory within approximately 5 minutes after notification. These data would then be transmitted to the large computers and used for the regional model calculations which would be available about 35 minutes after the trajectory calculation. These calculations would be repeated with updated environmental measurements and transmitted to the site until the requirement no longer exists. During the post-emergency period more detailed numerical model calculations can be made to assess the total environmental consequences of the toxic material release.

By FY 1979 we plan to have the central facility staffed 24 hours a day. During the interim 3-year period we will staff the central facility on a limited basis with the personnel on call during the off hours.

IV. Numerical Modeling and Environmental Assessment

In Chapter III we discussed and gave an example of the Gaussian diffusion estimate calculated at the site facility and based on the latest available meteorology measured at the local site. This calculation is designed to give the site personnel a quick estimate of expected normalized concentrations for distances out to 5 km. This chapter deals with advisories that are calculated at the central facility, transmitted to the site facility, and used to assess the regional consequences (out to 100 km) of an atmospheric release of toxic material. In large part, it is the development of these advanced regional modeling techniques that has made feasible an ARAC system on a nationwide basis.

Between the time that the Gaussian diffusion estimate is available and the time that the regional estimates are available, the central facility can send a trajectory prediction to the site within 5 minutes after notification. This calculation is intended to provide an early estimate of the extent of the downwind movement of the atmospheric release. Presently we have the capability to calculate a trajectory based on local meteorological measurements at the site and the national weather data reported by NWS or AFGWC. Supplemental data, as available from industries or other government agencies, will also be used to enhance this calculation. Other options for these interim calculations are under consideration, but are not presently available in the ARAC suite of model options.

For detailed regional assessments we presently have three-dimensional numerical transport and diffusion models that can be used operationally to estimate regional air concentrations and ground deposition from a continuous or instantaneous point source or sources. These models were used during the ARAC feasibility tests with Savannah River Laboratory.[2] MATHEW[3,4] is a meteorological data adjustment model which was developed to provide a transport and diffusion model (discussed below) with input wind fields which are mass-consistent, three-dimensional, and representative of the available meteorological measurements. The bottom boundary in this model is determined by the topographic features for a given site which play an important role in defining the local wind patterns. It must be emphasized that this computer code does not forecast the wind fields but uses available wind measurements over the region of interest to produce wind fields based on persistence. Presently research is under way at LLL as well as at other laboratories and agencies over the U. S. to develop fine-mesh meteorological predictive models. In keeping with the continuing research aspect of the ARAC concept, as these advanced models are validated and become available we will include them as an integral part of the model options available in the ARAC central facility. In the interim we plan to use forecast products that are available from NWS or AFGWC to help define changes in the meteorological conditions that might occur.

ADPIC[5-7] is a three-dimensional Cartesian particle-diffusion code, capable of calculating the time-dependent dispersion of inert radioactive air pollutants under many conditions including stratified shear flow, calms, topography, and wet and dry deposition. In addition this computer code has been adapted to simulate fallout patterns of particulates with given particle size distributions and plume depletion of particulates over various types of terrain.[8] This computer code has been velidated using measured iodine air concentration data taken during a tracer release at INEL,[6] Idaho Falls, and measured ^{41}Ar concentration data at the Savannah River Plant.[2] We plan to conduct further validation and sensitivity studies during FY 1976. MATHEW and ADPIC are now available to run operationally on the Livermore CDC 7600 computers. These codes can estimate air concentrations and ground deposition for any proposed site by inputting the local topography, potential source term(s), and location of available meteorological data. "Tuning" these models for each site is not necessary.

The ADPIC-calculated regional distribution of surface air concentrations and surface deposition of specific radionuclides of interest may be input to a dose-conversion computer code (DOSCON) for deriving the individual and population whole-body or organ doses via the inhalation, external, and ingestion pathways. By using the ICRP Task Group on Lung Dynamics Model,[9] one can compute the dose to various organs of the respiratory tract provided the aerodynamic particle size and the chemical and physical characteristics of the specific radionuclides are known. External exposures due to direct gamma radiation from gaseous plumes may be evaluated by integrating the activity over the volume of the plume. This has been demonstrated by Clarke[10] and in the case of noble gases by Kahn and Blanchard[11] and Russell and Galpin.[12] External exposures due to surface deposition of gamma-emitting radionuclides can be derived on the basis of the calculated photon flux per unit source strength and the flux-to-exposure-rate conversion factors presented by Beck et al.[13] The calculation of dose from ingestion of food, however, requires the use of reconcentration factors of radionuclides by biological processes to determine the activity of specific radionuclides in each food. These factors may be obtained from the data of Thompson et al.[14] Numerous models are available for the calculation of the ingestion dose through specific food-chain pathways. Most noted are the results of Ng et al.[15] and Killough et al.[16] Although these dose models are not presently available as ARAC models, we plan to include them during FY 1976.

Another prospect for the future is the extension of modeling techniques to aquatic systems. Research in this area is planned to start in FY 1977 so as to permit subsequent inclusion in the ARAC capabilities.

V. The ARAC Implementation Plan and Associated Costs

The initial three-phase study started at LLL in FY 1973 provided for concept, prototype, and implementation of ARAC. The prototype phase is ending in FY 1975, and a three-year implementation phase is now scheduled to establish the service with ERDA operational sites. This three-year plan contemplates an incremental building of the component parts of the ARAC system until a fully operating network of ERDA nuclear sites with the LLL central facility would be complete in FY 1978. The ARAC service may then be offered to additional sites.

FY 1976 will mark the initial implementation of the ARAC system. A series of major goals will be accomplished during FY 1976 that are consistent with the three-year implementation plan:

- A prototype site facility already established at LLL will be fully operational for the stand-alone mode, i.e., it will not be communicating with the central facility although the necessary communication software will be completed.
- Site facility hardware will be installed and the software customized for an ERDA research site (Savannah River Plant) and an ERDA operations site. These facilities will be operating in the stand-alone mode. During this interim period advisories can be received from the central facility via telecopier or other means.
- Hardware for the basic central-facility configuration will be purchased and the software development initiated. The operating system for the central facility requires extensive software effort, so the communications link between this facility and other sites will probably not be established until early in the following fiscal year.
- A real-time operating and data management code will be developed to run and monitor the principal regional transport and diffusion calculation (ADPIC). In addition, tailored output for LLL, SRL, and one other site will be designed to aid in the interpretation of the results of these calculations.
- A method for producing probabilistic concentration calculations based on uncertainties in the input data will be investigated. The utilization of forecast meteorological data such as output from the Air Force Boundary Layer Model will be investigated. These data will be factored into the site observational data in such a way as to provide forecast capabilities for the ARAC advisories.
- Validation and sensitivity studies for the ARAC models will continue.

In this plan, FY 1977 and FY 1978 would see the addition of two serviced sites in each year. Communication links between the LLL central facility and the first three ERDA sites are scheduled for early FY 1977.

A summary of the LLL costs estimated for the plan is contained in Table 1. ERDA funding will be budgeted by LLL with one exception. The site itself would have to fund the one-time operating costs for customizing the installed ARAC equipment at the site.

After completion of the three-year plan, the site would also bear its proportion of the recurring operations-related costs for the central facility. For FY 1979 and subsequent years these annual costs are estimated at $630,000 (plus inflation), plus about $200,000 of ERDA funding for continuing research-related activity on improving ARAC and modeling capability. The estimated ARAC costs to an ERDA nuclear site for the service are summarized in Table 2.

In addition, the site will have its costs for installing and operating the monitoring and sensor network which furnishes the basic input source data. The latter costs would be variable depending on each site, although operating costs to maintain the ARAC site equipment only are estimated at $10,000 per year.

Table 1. Estimated LLL costs for three-year ARAC implementation plan. These estimates are consistent with those proposed in discussions with representatives of DBER and DOS and are currently reflected in Schedule 189 submissions to ERDA for FY 1976 and 1977.

	Operating costs ($1000's)			Capital equipment cost ($1000's)		
	Research	Operations	Total	Research	Operations	Total
FY 1976	525[a]	135[b]	660	170	50	220
FY 1977	610	305[c]	915	60	100	160
FY 1978	600	400[c]	1000	50	100	150
Totals	1735	840	2575	280	250	530

[a]Includes site customizing for SRL.

[b]Includes site customizing for one additional ERDA site.

[c]Includes site customizing for two additional ERDA sites.

Table 2. Details of estimated ARAC costs for an ERDA site. Not included are the costs of establishing and operating a monitoring network.

	Cost ($1000's)
One-Time Costs	
Capital equipment (provided by ERDA):	
Minicomputer with core memory, graphic display, tape, teletype	32
Interface to weather data equipment	4
No-fail power supply	4
Printer/plotter	10
Total	50
LLL customizing and software (site responsibility)	75
Recurring Costs (Annual)	
Site operating expenses:	
Lease of phone lines, data set, ACU	1
Communication charges	4
Computer system maintenance	5
Total	10
Share in ARAC operations-related costs after FY 1978:	
If 7 sites	90
If 20 sites	30
If 100 sites	6

VI. Summary and Conclusions

The present status of the component parts of ARAC can be summarized as follows:

- Site facility. We have already established and equipped a prototype site facility at LLL. Software for the LLL site facility is written; this software can be customized for additional ERDA facilities as they become users of ARAC.

- Meteorological data acquisition facility. National Weather Service data are now available and AFGWC links are being arranged. Minicomputer hardware has been purchased for this system and software for the operating system is in the initial stages of development. This facility is expected to be operating by late 1975 or early 1976.

- Central facility. LLL has conducted trial exercises in a prototype facility; a permanent installation is being prepared. Specifications have been written for the minicomputer hardware which will be purchased in FY 1976. Software for the operating system will be written during FY 1976 with communications to three ERDA sites expected early in FY 1977.

- Regional assessment and numerical modeling. Computer codes are presently available to compute trajectories and regional concentrations. We now have the capability to estimate individual dose through various pathways due to a radionuclide release.

During FY 1976 we plan to provide two additional ERDA sites with a customized site facility in addition to continuing the research and development of the other ARAC component parts. Early in FY 1977 the ARAC advisory service from the central facility will be available to these sites on the minicomputer graphic display.

It should be recognized that ARAC represents a concept which is in the initial stages of being implemented. This emerging nature of ARAC means that changes can be expected before it reaches its final form. However, the concept of ARAC is fully developed and was successfully demonstrated during a feasibility study conducted in FY 1974 as a joint effort between the Savannah River Laboratory (SRL) and LLL.[2] The concept also received a realistic check in May of 1974 when the Savannah River Plant (SRP) experienced a relatively low level atmospheric release of tritium.[17] Although the feasibility tests were not completed at this time, the real-time meteorological data link between SRL and LLL was established. Meteorological measurements from the instrumented TV tower near SRP coupled with calculations based on simple LLL models provided SRL personnel with supplemental and timely information which was used in assessing the potential hazard from the release.

We have attempted, in this report, to present enough about the concept, current status, and future plans to give users a perspective on the limitations as well as the potential advantages of ARAC. While our immediate goal is the application of ARAC to assist a limited number of ERDA sites, the system is designed with sufficient flexibility to permit expanding the service to a larger number of sites. Success in ARAC application should provide significant impact in permitting the nuclear facilities to handle better the urgent questions concerning the potential hazards from atmospheric releases.

References

1. M. H. Dickerson, J. B. Knox, J. J. Cohen, and R. C. Orphan, A Concept for an Atmospheric Release Advisory Capability, Lawrence Livermore Laboratory Rept. UCRL-51656 (1974).
2. M. H. Dickerson, C. Kern (SRL), et al., "Feasibility Tests of the Atmospheric Release Advisory Capability (ARAC)," to be published August 1975.
3. C. A. Sherman, A Mass-Consistent Model for Wind Flows Over Complex Terrain, Lawrence Livermore Laboratory Rept. UCRL-76171 (1975).
4. C. A. Sherman, MATHEW: A Mass-Consistent Wind Field Model, Ph. D. Thesis, U. C.-Davis, to be published.
5. R. Lange, ADPIC—A Three-Dimensional Computer Code for the Study of Pollutant Dispersal and Deposition Under Complex Conditions, Lawrence Livermore Laboratory Rept. UCRL-51462 (1973).
6. R. Lange and J. B. Knox, Adaption of a Three-Dimensional Atmospheric Transport and Diffusion Model to Rainout Assessments, Lawrence Livermore Laboratory Rept. UCRL-75731 (1974).
7. R. Lange, ADPIC—A Three-Dimensional Transport-Diffusion Model for the Dispersal of Atmospheric Pollutants and Its Validation Against Regional Tracer Studies, Lawrence Livermore Laboratory Rept. UCRL-76170 (1975).
8. P. H. Gudiksen, K. R. Peterson, R. Lange, and J. B. Knox, Plume Depletion Following Postulated Plutonium Dioxide Releases From Mixed Oxide Fuel-Fabrication Plants, Lawrence Livermore Laboratory Rept. UCRL-51781 (1975).
9. International Commission on Radiological Protection, Task Group on Lung Dynamics, "Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract," Health Physics 12, 173 (1966).
10. R. H. Clarke, "The Weerie Program for Assessing the Radiological Consequences of Airborne Effluents from Nuclear Installations," Health Physics 25, 267 (1973).
11. B. Kahn and R. L. Blanchard, Radiological Surveillance Studies at a Boiling Water Nuclear Power Reactor, Public Health Service, Bureau of Radiological Health, Rockville, Md., BRH/DER 70-1 (1970).
12. J. L. Russell and F. L. Galpin, Comparison of Techniques for Calculating Doses to the Whole Body and to the Lungs from Radioactive Noble Gases, Environmental Protection Agency, Technology Assessment Division, Rockville, Md. (1971).
13. H. L. Beck, J. DeCampo, and C. Gogolak, In-Situ Ge(Li) and NaI(Tl) Gamma-ray Spectrometry, U.S. Atomic Energy Commission, Health and Safety Laboratory, New York, N.Y., HASL-258 (1972).
14. S. E. Thompson, C. A. Burton, D. J. Quinn, and Y. C. Ng, Concentration Factors of Chemical Elements in Edible Aquatic Organisms, Lawrence Livermore Laboratory Rept. UCRL-50564 (1972).

15. Y. C. Ng, C. A. Burton, S. E. Thompson, R. K. Tandy, H. K. Kretna, and M. W. Pratt, Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, Part 4, Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere, Lawrence Livermore Laboratory Rept. UCRL-50163 Part 4 (1968).
16. G. G. Killough, P. S. Rohwer, and W. D. Turner, INREM—A Fortran Code Which Implements ICRP 2 Models of Internal Radiation Dose to Man, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL-5003 (1975).
17. W. L. Marter, Environment Effects of a Tritium Gas Release From the Savannah River Plant on May 2, 1974, E. I. du Pont de Nemours & Co., DP-1369 UC-11 (1974).

WEC bl lmc